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Alterations in Scapular Force Couple Ratios in Patients with Rotator Cuff Syndrome

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Abstract: *Background:* Scapular force couple imbalance may contribute to abnormal shoulder mechanics in patients with rotator cuff syndrome. *Objective:* To compare scapular muscle strength, myoelectric activity and force couple ratios between the injured and non-injured sides in patients with unilateral rotator cuff syndrome. Methods: Thirty patients with mean ± SD age of 35.9 ± 8.94 years were assessed using handheld dynamometry and surface Electromyography (EMG). Paired statistical tests were conducted to compare sides and evaluate force couple ratios. Results: Injured shoulders exhibited significantly reduced strength in the upper trapezius, lower trapezius, and serratus anterior muscles ($P < 0.05$). EMG revealed significantly increased upper trapezius activation and elevated upper trapezius / serratus anterior ratio on the injured side ($P < 0.05$). *In Conclusion:* Rotator cuff syndrome is associated with altered scapular force couples and neuromuscular imbalance, emphasizing the need for targeted rehabilitation.

Key words: Rottor Cuff Syndrome・Force Couple Ratio・Electromyography・Strength

INTRODUCTION

Rotator cuff syndrome (RCS) is one of the most common causes of shoulder pain and dysfunction [1]. The rotator cuff is formed by the combined muscle bellies and tendons of the supraspinatus, infraspinatus, teres minor, and subscapularis muscles, which surround and support the shoulder joint. RCS refers to a range of disorders involving injury or degeneration of these structures [1, 2]. This includes conditions such as subacromial impingement syndrome, bursitis, rotator cuff tendinitis, and partial or full-thickness tendon tears. When rotator cuff problems become chronic, they may increase the risk of developing glenohumeral joint degeneration and rotator cuff arthropathy [1-3].

Dysfunction of the scapular stabilizing muscles may contribute to altered glenohumeral kinematics and exacerbate impingement or tendon degeneration [4]. The scapular force couple–primarily involving the upper trapezius (UT), middle trapezius (MT), lower trapezius (LT), and serratus anterior (SA)-plays a critical role in stabilizing the scapula during arm elevation [4, 5].

The rhythmic movement between the scapula and humerus is known as the scapulohumeral rhythm and it is controlled by the integration between three-dimensional pattern of motion of glenohumeral joint and scapulothoracic articulation [4, 5]. In this rhythm, the scapula acts as a stable base and the glenohumeral joint moves to position the arm safely in the desired range of motion [6, 7].

Proper coordination between scapular elevation and upward rotation with humeral movement is crucial for maintaining subacromial space during arm elevation and ensuring muscle efficiency [8, 9]. Scapular malposition can disrupt the length-tension relationship, reducing muscle force output [10]. This positioning is regulated by coordinated muscle groups, or force couples-primarily the UT, LT, and SA for upward rotation; LT and SA for posterior tilt and external rotation; and the rhomboids and levator scapulae for downward rotation [11]. Kinematic changes are often linked to increased UT activity and decreased SA and rotator cuff activation [11], contributing to RCS development [12,13].

Moreover, researchers such as Cools *et al*. (2007, 2014) emphasized the need to evaluate scapular muscle function in terms of relative balance, introducing the concept of scapular force couple ratios. The UT/LT and UT/SA activity ratios offer insight into the dominance or

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deficiency of muscle groups working in opposition or synergy. Alterations in the balance or strength of these muscles can lead to scapular dyskinesis, a known risk factor in RCS and Rotator cuff syndrome [14, 15].

Kibler and colleagues described how altered scapular force couples reduce scapular posterior tilt and upward rotation, leading to a narrowed subacromial space [16, 17]. Similarly, Struyf *et al.* [18] found a strong association between these altered muscle patterns and symptoms such as pain, range of motion limitation, and functional disability.Interestingly, research by Castelein *et al.* [19] found that restoration of the UT/LT and UT/SA ratios through specific exercise programs led to significant clinical improvements in patients with RCS, further highlighting the utility of these ratios as both diagnostic and therapeutic indicators.

While individual muscle activity (e.g., of the SA or UT) has been studied extensively, the dynamic balance between force couples-particularly the ratios between stabilizing muscles like the UT/LT and UT/SA-remains underexplored. Understanding these ratios can reveal functional imbalances that are not evident when analyzing muscles in isolation. So, this study aimed to compare scapular force couple ratios (UT/LT and UT/SA) between the injured and non-injured sides in individuals with unilateral RCS.

MATERIALS AND METHODS

Participants: Thirty patients (age range: 25-50 years; 14 males, 16 females) with unilateral RCS were referred by an orthopedist. Patients' diagnosis with RCS was verified by following the structured physical examination introduced by Jain *et al.* [20]. Patients were included in the study if they fulfilled at least 50% of Shoulder Pain and Disability Index (SPADI), this value ensured more homogenous sample. The patients should have at least three positive signs from those introduced by Jain *et al.* [20] such as Neer's [21], Hawkin's [22] and Jobe's [23] signs. Positive Neer's sign means reproduction of pain when the humerus is flexed to the end of range with over pressure [21]. Positive Hawkin's sign means reproduction of pain when the shoulder is passively placed in 90° forward flexion and internally rotated to the end of range [22]. Positive Jobe's sign means, reproduction of pain and lack of force production during isometric shoulder elevation in the scapular plane while the shoulder is placed in internal rotation [23].

Patients were excluded if they had history of shoulder dislocation, shoulder surgery, current symptoms related to cervical spine affection, previously diagnosed structural injuries to the shoulder complex and/or being athlete.

Outcome Measures:

1. Electromyographic measurements: DELSYS INC Myomonitor (Delsys INC., USA) Electromyography (EMG) System was used for assessing the myoelectric activities of the UT, LT and SA muscles. It is an eight channels, dual-mode portable EMG and physiological signal data acquisition system. Patient's hair at sites of electrode placement was shaved when needed and the skin was cleaned with alcohol to remove skin debris. Sites of EMG sensors placement (Table 1) was determined by using marker pen and tape measurement [24].

After EMG sensor placement, the patients stood beside the custom-made device (a metallic stand with a white board fixed above it) which was oriented 30 degrees anterior to the frontal plane to standardize the upper extremity position to simulate scapular plane motion [25]. This position is recommended for assessment of upper limb movement as it provides the best mechanical advantage for the action of the glenohumeral muscles, and it is used for most daily activities (simulate a functional range). The patients were instructed to keep their elbows extended and slide their arms across the board of the device [26], through a range of 30º -120º of arm elevation to avoid pain reproduction that might occur beyond 120 degree.

The examiner stood in front of the patients to guide the motion and to prevent any substitutions of the trunk by supporting the opposite shoulders if needed. Three

Table 1: Patient positioning and EMG sensor placement for measuring the myoelectric activity of the scapular rotators during arm elevation in patients with unilateral rotator cuff syndrome

Tested muscle	Patient positioning and EMG sensor placement
Upper Trapezius	While the arm being rested at the side of the body, the sensor was placed on a straight horizontal line midway between theC7 spinous process and the lateraledge of the acromion process.
Lower Trapezius	While the shoulder was in maximum flexion, the EMG sensorwas placed obliquely approximately5-cm lateral to the spinous process, at the level of the inferiorangle of the scapula.
Serratus anterior	While the arm at 90 degreesof flexion, the EMG sensor was placed just lateral to the inferior angle of the scapulaand anterior to the latissimus dorsi muscle.The reference electrode was applied on the patella at the knee joint which is an electrically inactive area.

Table 2: Patient positioning and Hand-held Dynamometer placement for measuring the isometric muscle strength of the scapular rotators in patients with unilateral rotator cuff syndrome

Tested muscle	Patient positioning and HHD placement
Upper Trapezius	The HHD device was placed over the superior border of the scapula. The examiner's resistance force was applieddirectly downward through the HHD device in the directionof scapular depression. Scapular elevation was the tested scapularmotion for the UT muscle where the patients were asked to elevate their shoulders as much as possible.
Lower Trapezius	The HHD device was placed over the spine of the scapula midway between the acromion process andthe root of the spine. The examiner's force was applied in a superior and lateral direction parallel to the long axis of the humerus, while the patient's arm was at 140 degrees of elevation and the patient in prone lying position. The scapula moved in adduction and depression. The patients were instructed to point their thumbs up then move the whole arm upward.
Serratus anterior	The HHD device was placed over theulna at the olecranon process. The examiner's resistance was applied downward to the olecranon process along the long axis of the humerus, while the patient's shoulder placed in 105 degrees horizontal adduction; this position was chosen as the optimal test position for the SA muscle because of less contribution from the pectoralis major muscles [27]. The elbow joint placed in 90 degrees of flexion, and the triceps muscle was monitored visually and by palpationto ensure that it did not contribute to force production during SA muscle test. The tested scapular motion for the SA was scapularprotraction. The patients were instructed to push their arms upward, while the examiner supported the shoulder girdle [24].

repetitions were performed. The injured shoulders were tested first followed by the non-injured one. All patients performed three familiarization trials before data collection, and they all received the same verbal command. The mean amplitudes of the EMG activities were the measured values.

2. Force Testing Using Hand-Held dynamometer (HHD): The Lafayette Manual Muscle Test System (Model 01163) is a hand-held dynamometer(HHD) used for objective quantification of isometric muscle strength of the UT, LT, and SA on both the injured and non-injured sides. Using the HHD, the peak force required to break an isometric contraction (break test) or the peak force that match the isometric contraction (make test) are measured as the examiner applies force against the subject. The HHD was applied to the subject in the direction opposite to the direction of the tested muscle'saction. For testing the peak isometric muscle forces, the resistance was gradually applied via the HHD deviceuntil the examiner matched the patient's effort (make test). Patient positioning and HHD placement during testing were shown in Table 2.

All patients performed one familiarization trial before data collection, and they all received the same verbal command. Three repetitions were performed of the three tested muscles in a random order. The mean value was used for statistical analysis. Force couple ratios (UT/LT and UT/SA) were calculated from both HHD and EMG data.

Statistical Analysis: All statistical measures were performed through the Statistical Package for Social Studies (SPSS) version 20 for windows. Data were screened for normality assumption, homogeneity of variance, and presence of extreme scores. Paired t-tests or Wilcoxon signed-rank tests (based on normality) were used to compare sides. Effect sizes were calculated for parametric data. The alpha level for the analysis was set at 0.05.

RESULTS

The statistical analysis for the patient demographic data revealed that the tested sample age, weight, and height ranged from 25 to 50 years, 55 to 86 kg, and 156 to 180 cm respectively with mean ± SD values of 35.9 ± 8.94 years, 70.58 ± 9.86 kg, and 1.66 ± 0.075 m respectively.

Statistical analysis revealed that the recorded mean amplitudes of UT EMG activity was significantly higher on the injured side than the non-injured side [$t(29) = 4.16$, $P < .001$, $d = 0.76$]. There were no significant differences in EMG-based activity of LT or SA.

Regarding the maximum isometric muscle force measured by the HHD, paired t-tests revealed significantly reduced strength on the injured side for the UT compared to the non-injured side [$t(29) = -6.38$, $P <0.001$, $d = -1.16$]. Similarly, LT strength was lower on the injured side than the non-injured side [$t(29) = -4.09$, $P <0.001$, $d = -0.75$]. SA strength also showed a statistically significant reduction ($Z = 105.00$, $p = 0.008$, Wilcoxon test).

Among the force couple ratios, only the EMG-based UT/SA ratio differed significantly between sides ($Z = 83.50$, $p = 0.002$), indicating altered neuromuscular coordination. The conducted statistical analyses were shown in Table 3.

Table 3: Comparisons for the scapular muscles myoelectric activities, muscle strength and force couple ratios between the injured and non-injured sides in patients with unilateral rotator cuff syndrome

Variables	Injured side	Non-injured side	Test statistics	p-value	Effect Size (Cohen's d)
UT-EMG	41.32 ± 15.970	30.89 ± 14.090	t= 4.16	< 0.001*	0.76
LT-EMG	28.29 ± 9.250	31.32 ± 20.220	Z= 210.00	0.655	–
SA-EMG	19.41 ± 8.850	19.62 ± 8.670	t= -0.18	0.861	-0.03
UT-HHD	20.12 ± 8.960	25.77 ± 6.250	t= -6.38	< 0.001*	-1.16
LT-HHD	10.57 ± 5.030	14.59 ± 4.760	t= -4.09	< 0.001*	-0.75
SA-HHD	13.47 ± 4.290	16.98 ± 6.290	Z=105.00	0.008*	–
UT/LT-EMG	1.62 ± 0.779	1.37 ± 0.930	t= 1.82	0.079	0.33
UT/SA-EMG	2.46 ± 1.430	1.71 ± 0.810	Z=83.50	0.002*	–
UT/LT-HHD	2.05 ± 0.720	1.86 ± 0.477	t= 1.30	0.206	0.24
UT/SA-HHD	1.54 ± 0.749	1.69 ± 0.660	Z=138.00	0.052	–

* Significant at alpha level 0.05, data are expressed as mean ±SD, UT= upper trapezius, LT=lower trapezius, SA= Serratus anterior, EMG= electromyography based measure, HHD= hand-held dynamometer based measure, t= t-value for the paired t-test, z= z-value for Wilcoxon signed-rank test.

DISCUSSION

This study aimed to quantify and compare scapular muscles EMG activities, strength and force couple ratios- specifically the UT/LT and UT/SA ratios–between the injured and non-injured sides for participants with RCS. Based on previous research findings, we anticipated that individuals with RCS would exhibit significantly elevated ratios, reflecting a pattern of UT dominance and compensatory dysfunction of the LT and SA.

In the most of the previous literature the EMG changes of scapular rotators include increased activities of the UT muscle and decreased activities of the SA muscle. The results of our investigation provided some support for this premise. The current study showed significant increased activities of the UT muscle and non-significant decrease in the activities of the SA and LT muscles, which agree with many previous studies. There was significant increase in the UT myoelectric activities at the RCS group compared with the control healthy group in almost all previous conducted studies [14,28,29]. This overactivity of the UT is often interpreted as a compensatory response to weakness or delayed activation in the LT and SA muscles, both of which are critical for proper scapular motion[30].

Contrary to some expectations, LT and SA EMG activity did not differ significantly between sides. This partially contradicts findings by De Mey *et al.* [31] who reported reduced LT and SA activation in RCS patients. The discrepancy may stem from differences in task specificity or measurement protocols. Notably, EMG normalization and patient-specific compensatory strategies could mask subtle changes in LT and SA firing patterns.

The non-significant differences in the EMG activities of the LT and SA muscles reported in our study may be attributed to the methodological difficulties that occurred during measuring the shoulder complex myoelectric activities. When using surface EMG on relatively small muscles of the shoulder complex, crosstalk (detection of EMG signal from muscles other than the one of interest) might have happened and this issue might have affect the accuracy of the collected data [32].

Moreover, the non-significant findings in the EMG data of the LT and SA muscles may be attributed to difference in the study design. As in the current study, we compared the myoelectric activities of the injured sides in patients with unilateral RCS with those of the non-injured sides in the same patients (intra-subject comparison). While many studies found significant changes in the myoelectric activities of scapular rotators as they compared the myoelectric activities of the injured sides of the RCS group with those of the corresponding sides of the tested healthy control group.

Regarding the peak isometric UT, LT, and SA muscle forces, findings revealed that there was a statistical significant difference between the injured and non-injured sides, with the injured sides having less force than the non-injured sides. These findings support prior work by previous researchers [14, 33, 34], who emphasized the role of weakened scapular stabilizers–especially the LT and SA–in contributing to abnormal scapular kinematics in RCS. The current results extend this by quantifying strength asymmetry within-subjects using handheld dynamometry, offering practical relevance for clinicians without access to isokinetic testing.

The decreased LT and SA strength may impair the scapula's ability to upwardly rotate and posteriorly tilt during arm elevation, increasing the risk of subacromial compression. Although UT strength was also reduced, this finding diverges from some previous studies, such as Kibler *et al.* [35], which suggested UT overactivity rather than weakness in RCS patients. However, this discrepancy may be explained by compensatory UT activation patterns rather than true hypertrophy or strength increases.

Thus, the findings of our study confirm significant muscular and neuromuscular alterations in patients with RCS. The observed UT hyper-activation and decreased force couple balance support existing models of scapular dyskinesis contributing to rotator cuff pathology. These findings are consistent with prior research [14, 33, 34] and highlight the need for targeted strengthening and neuromuscular retraining.

Among the force couple ratios analyzed, only the UT/SA EMG ratio was significantly elevated on the injured side. This result is particularly relevant because it reflects an imbalanced activation pattern that favors UT dominance over SA, a hallmark of scapular dyskinesis. This supports the theoretical model proposed by Kibler and McMullen (2003), where force couple imbalances disrupt scapular control, contributing to mechanical impingement [13].

Interestingly, the UT/LT and UT/SA ratios derived from HHD data were not significantly different. This may suggest that EMG-based force couples are more sensitive indicators of functional imbalance than static strength ratios, echoing the views of Phadke *et al.* [11] who emphasized the value of assessing timing and coordination, not just force magnitude.

An increased UT/LT EMG ratio suggests an imbalance within the trapezius muscle group, which plays a pivotal role in scapular upward rotation and posterior tilt. Over-activation of the UT in the absence of adequate LT contribution may lead to excessive scapular elevation. Likewise, an increased UT/SA ratio implies that the scapula may be rotating upward via elevation and internal rotation rather than a smooth coordinated movement, reducing the subacromial space and contributing to tendon impingement.

Understanding force couple imbalances in RCS opens the door to more targeted rehabilitation strategies. For example, traditional strengthening protocols may not adequately address these imbalances if they do not normalize the UT/LT and UT/SA ratios. Interventions might include exercises such as prone Y raises, side-lying external rotation, and dynamic push-up plus, which have shown to selectively activate LT and SA while minimizing UT overactivity.

Clinical Implications: These findings carry meaningful implications for rehabilitation. The presence of both strength deficits and neuromuscular imbalance suggests that interventions should target both muscle strengthening and motor control retraining. Specifically, programs focusing on LT and SA activation (e.g., prone Y-raises, dynamic hug) combined with UT inhibition strategies (e.g., biofeedback or scapular repositioning) may help restore optimal scapular mechanics. The significant UT/SA EMG imbalance also suggests the need for functional retraining over isolated strengthening.

Limitations: Despite the study's strengths, including within-subject comparisons and concurrent EMG/HHD measurement, several limitations must be acknowledged. Surface EMG can be influenced by electrode placement, skin impedance and cross-talk from neighboring muscles. Moreover, it may not capture the full complexity of three-dimensional scapular motion. The cross-sectional design also limits causal inferences, and the manual positioning during HHD testing may introduce variability.

Future Directions: Future research should explore longitudinal changes in force couple ratios following rehabilitation, the use of 3D motion analysis, and sex- or activity-level differences in scapular force couple dynamics.

CONCLUSION

In summary, this study confirms that patients with RCS exhibit significant scapular muscle weakness and an elevated UT/SA EMG ratio on the injured side, indicating both strength and motor control impairments. These findings support a multifactorial approach to rehabilitation, emphasizing the correction of neuromuscular imbalance alongside strength restoration to improve scapular function and reduce impingement symptoms.

REFERENCES

1. Oh, L.S., B.R. Wolf, M.P. Hall, B.A. Levy and R.G. Marx, 2007. Indications for rotator cuff repair: a systematic review. Clin. Orthop Relat Res., 455: 52-63.
2. Farfaras, S., N. Sernert, L. Rostgard Christensen, E.K. Hallström and J.T. Kartus, 2018. Subacromial Decompression Yields a Better Clinical Outcome Than Therapy Alone: A Prospective Randomized Study of Patients With a Minimum 10-Year Follow-up. Am. J. Sports Med., 46(6): 1397-1407.

3. Yamaguchi, K., K. Ditsios, W.D. Middleton, C.F. Hildebolt, L.M. Galatz and S.A. Teefey, 2006. The demographic and morphological features of rotator cuff disease. A comparison of asymptomatic and symptomatic shoulders. J. Bone Joint Surg Am., 88(8): 1699-1704.
4. McClure, P., A.R. Tate, S. Kareha, D. Irwin and E. Zlupko, 2009. A clinical method for identifying scapular dyskinesis, part 1: reliability. Journal of Athletic Training, 44(2): 160-164.
5. Crosbie, J., S.L. Kilbreath, L. Hollmann and S. York, 2008. Scapulohumeral rhythm and associated spinal motion. Clinical Biomechanics. 23(2): 184-92.
6. Keshavarz, R., S.B. Tajali, S.M. Mir and H. Ashrafi, 2017. The role of scapular kinematics in patients with different shoulder musculoskeletal disorders: a systematic review approach. Journal of Bodywork and Movement Therapies, 21(2): 386-400.
7. Laudner, K.G., J.B. Myers, M.R. Pasquale, J.P. Bradley and S.M. Lephart, 2006. Scapular dysfunction in throwers with pathologic internal impingement. Journal of Orthopaedic & Sports Physical Therapy, 36(7): 485-494.
8. Timmons, M.K., C.A. Thigpen, A.L. Seitz, A.R. Karduna, B.L. Arnold and L.A. Michener, 2012. Scapular kinematics and subacromial-impingement syndrome: a meta-analysis. Journal of Sport Rehabilitation, 21(4): 354-370.
9. Ratcliffe, E., S. Pickering, S. McLean and J. Lewis, 2014. Is there a relationship between subacromial impingement syndrome and scapular orientation? A systematic review. British Journal of Sports Medicine, 48(16): 1251-6.
10. Myers, J.B., K.G. Laudner, M.R. Pasquale, J.P. Bradley and S.M. Lephart, 2005. Scapular position and orientation in throwing athletes. The American Journal of Sports Medicine, 33(2): 263-71.
11. Phadke, V., P.R. Camargo and P.M. Ludewig, 2009. Scapular and rotator cuff muscle activity during arm elevation: a review of normal function and alterations with shoulder impingement. Brazilian Journal of Physical Therapy, 13: 1-9.
12. Blanch, P., 2004. Conservative management of shoulder pain in swimming. Physical Therapy in Sport, 5(3): 109-24.
13. Kibler, B.W. and J. McMullen, 2003. Scapular dyskinesis and its relation to shoulder pain. JAAOS-journal of the American Academy of Orthopaedic Surgeons, 11(2): 142-51.
14. Cools, A.M., G.A. Declercq, D.C. Cambier, N.N. Mahieu and E.E. Witvrouw, 2007. Trapezius activity and intramuscular balance during isokinetic exercise in overhead athletes with impingement symptoms. Scandinavian Journal of Medicine & Science in Sports. 17(1): 25-33.
15. Cools, A.M., F. Struyf, K. De Mey, A. Maenhout, B. Castelein and B. Cagnie, 2014. Rehabilitation of scapular dyskinesis: from the office worker to the elite overhead athlete. British Journal of Sports Medicine, 48(8): 692-697.
16. Kibler, W.B., T. Wilkes and A. Sciascia, 2013. Mechanics and pathomechanics in the overhead athlete. Clinics in Sports Medicine, 32(4): 637-651.
17. Kibler, W.B. and A.D. Sciascia, 2017. Editors. Disorders of the scapula and their role in shoulder injury: a clinical guide to evaluation and management. Springer; May 27.
18. Struyf, F., B. Cagnie, A. Cools, I. Baert, J. Van Brempt, P. Struyf and M. Meeus, 2014. Scapulothoracic muscle activity and recruitment timing in patients with shoulder impingement symptoms and glenohumeral instability. Journal of Electromyography and Kinesiology, 24(2): 277-284.
19. Castelein, B., B. Cagnie, T. Parlevliet and A. Cools, 2016. Scapulothoracic muscle activity during elevation exercises measured with surface and fine wire EMG: a comparative study between patients with subacromial impingement syndrome and healthy controls. Manual Therapy. 23: 33-39.
20. Jain, N.B., R.B. Wilcox 3rd, J.N. Katz and L.D. Higgins, 2013. Clinical examination of the rotator cuff. PM R. 5(1): 45-56.
21. Neer, C.S., 1983. Impingement lesions. Clin Orthop, 173: 70-77.
22. Hawkins, R.J. and D.J. Bokor, 1990. The shoulder. Philadelphia: WB Saunders Co.
23. Cools, A.M., E.E. Witvrouw, G.A. Declercq, G.G. Vanderstraeten and D.C. Cambier, 2004. Evaluation of isokinetic force production and associated muscle activity in the scapular rotators during a protraction-retraction movement in overhead athletes with impingement symptoms. British Journal of Sports Medicine, 38(1): 64-68.
24. Michener, L.A., N.D. Boardman, P.E. Pidcoe and A.M. Frith, 2005. Scapular muscle tests in subjects with shoulder pain and functional loss: reliability and construct validity. Physical Therapy, 85(11): 1128-38.

25. Moraes, G.F., C.D. Faria and L.F. Teixeira-Salmela, 2008. Scapular muscle recruitment patterns and isokinetic strength ratios of the shoulder rotator muscles in individuals with and without impingement syndrome. Journal of Shoulder and Elbow Surgery, 17(1): S48-53.
26. Smith, M., V. Sparkes, M. Busseand S. Enright, 2009. Upper and lower trapezius muscle activity in subjects with subacromial impingement symptoms: is there imbalance and can taping change it? Physical Therapy in Sport, 10(2): 45-50.
27. Wang, S.S., S.O. Normile and B.T. Lawshe, 2006. Reliability and smallest detectable change determination for serratus anterior muscle strength and endurance tests. Physiotherapy Theory and Practice. 22(1): 33-42.
28. Bandholm, T., L. Rasmussen, P. Aagaard, B.R. Jensen and L. Diederichsen, 2006. Force steadiness, muscle activity, and maximal muscle strength in subjects with subacromial impingement syndrome. Muscle & Nerve: Official Journal of the American Association of Electrodiagnostic Medicine, 34(5): 631-639.
29. Faria, C.D., L.F. Teixeira-Salmela, F.R. de Paula Goulart and G.F. Moraes, 2007. Scapular Muscle Actions During Lowering of the Arms with Shoulder Impingement Syndrome. Journal of Biomechanics, 40(2): S637.
30. Wadsworth, D.J. and J.E. Bullock-Saxton, 1997. Recruitment patterns of the scapular rotator muscles in freestyle swimmers with subacromial impingement. International Journal of Sports Medicine, 18(08): 618-624.
31. De Mey, K., L. Danneels, B. Cagnie and A.M. Cools, 2012. Scapular muscle rehabilitation exercises in overhead athletes with impingement symptoms: effect of a 6-week training program on muscle recruitment and functional outcome. The American Journal of Sports Medicine, 40(8): 1906-1915.
32. Chester, R., T.O. Smith, L. Hooper and J. Dixon, 2010. The impact of subacromial impingement syndrome on muscle activity patterns of the shoulder complex: a systematic review of electromyographic studies. BMC Musculoskeletal Disorders, 11: 1-2.
33. Ludewig, P.M. and J.P. Braman, 2011. Shoulder impingement: biomechanical considerations in rehabilitation. Manual Therapy, 16(1): 33-39.
34. Chen, W.Y., S.L. Ma, M.W. Tai, T.J. Wang, C.T. Chen and Y.C. Kao, 2007. Relationships of Scapular Alignment, Strength and Shoulder Rotator Function in Overarm Throwing Athletes. Journal of Biomechanics, 40(2): S391.
35. Kibler, W.B., A.D. Sciascia, T.L. Uhl, N. Tambay and T. Cunningham, 2008. Electromyographic analysis of specific exercises for scapular control in early phases of shoulder rehabilitation. The American Journal of Sports Medicine, 36(9): 1789-1798.